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(54) **Slurry casting of metals**

(57) Metallic slurry is produced by agitating a metallic material at a temperature between its liquidus and its solidus, by means of a reciprocating agitator. The metallic slurry can be produced in a vessel 3 with a reciprocating agitator 10, and the agitator may also serve as a piston for discharging slurry from the vessel into a mould or die. The agitator may take the form of a perforated or serrated disc 19, 21 and may also be provided with operable flap members 25 to control the mixing action and discharge of the slurry.

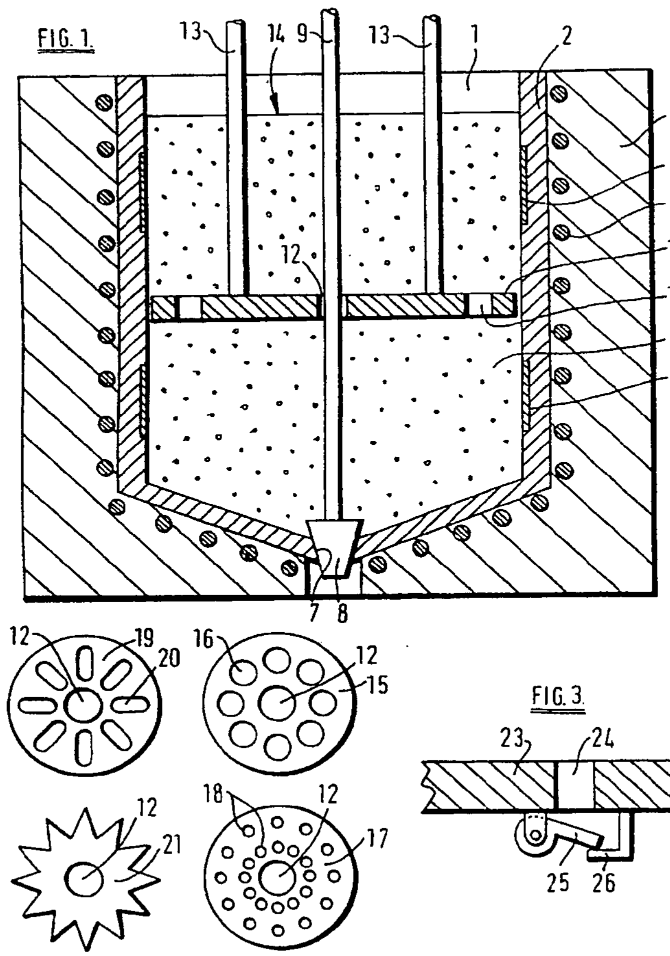

FIG. 1.

FIG. 2.

FIG. 3.

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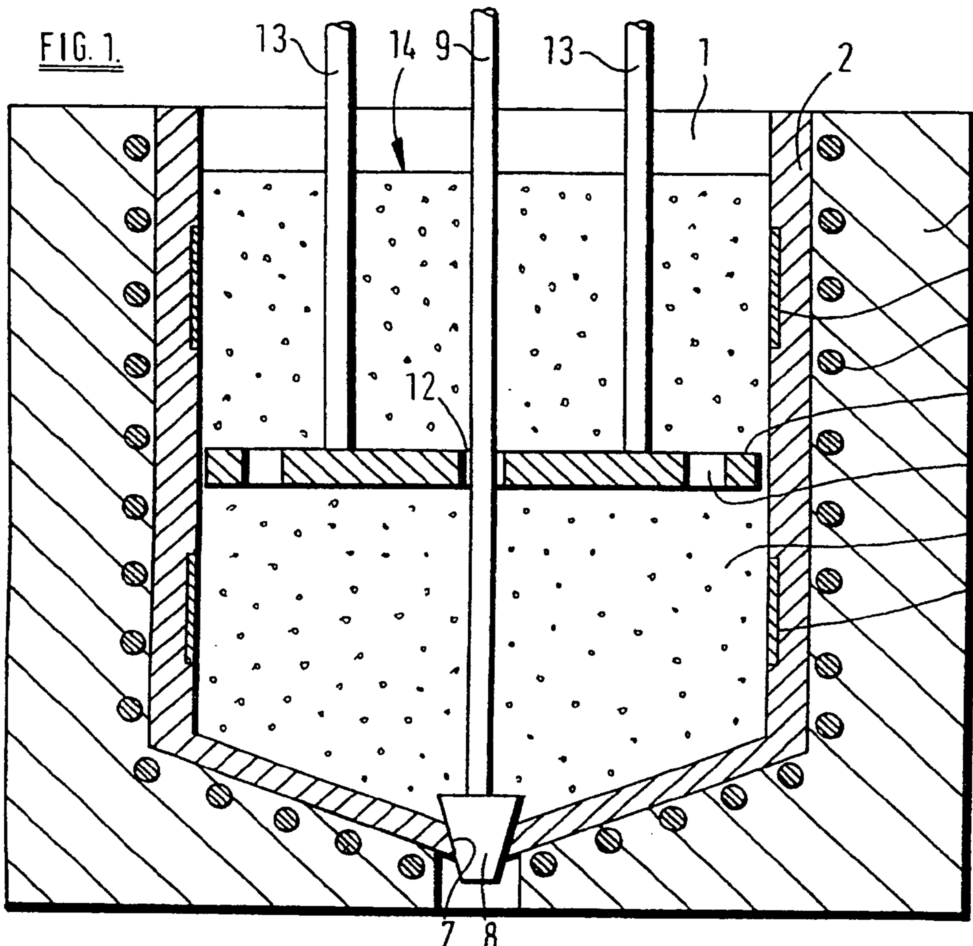
The drawing(s) originally filed was/were informal and the print here reproduced is taken from a later filed formal copy.

FIG. 1.



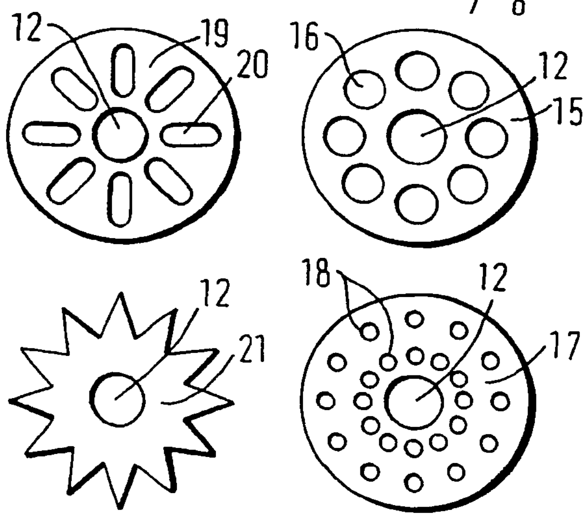
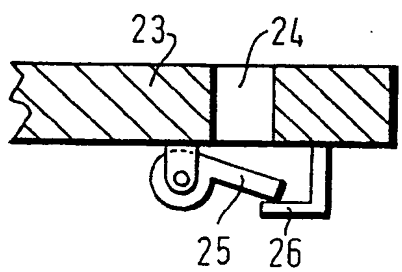


FIG. 2.

FIG. 3.



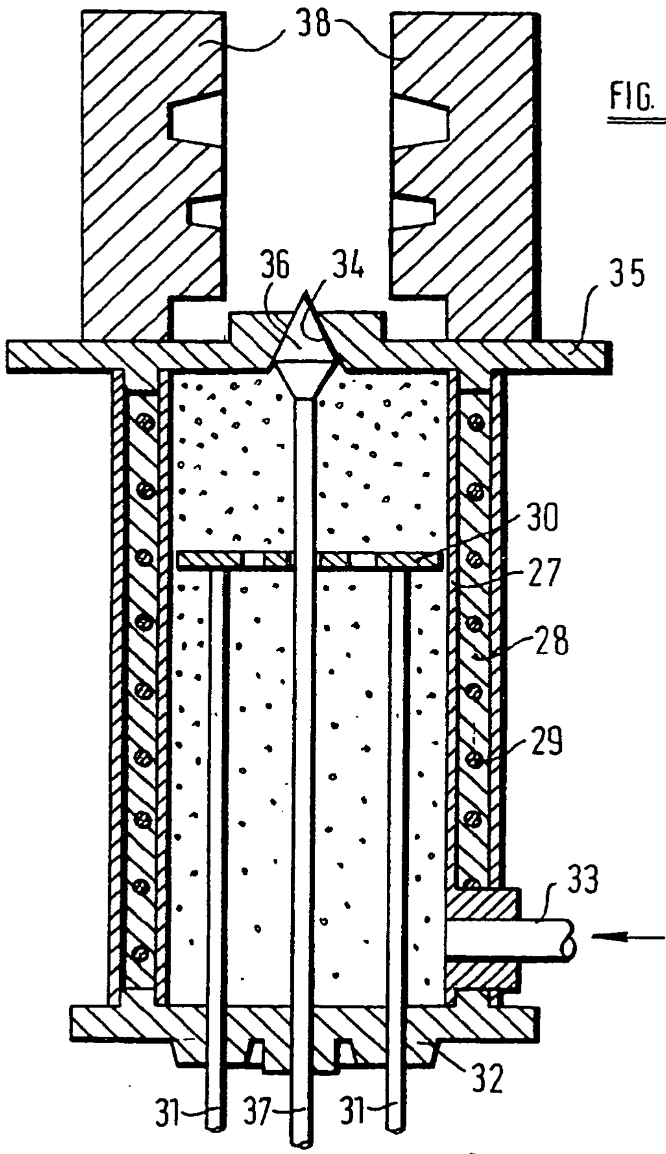


FIG. 4.

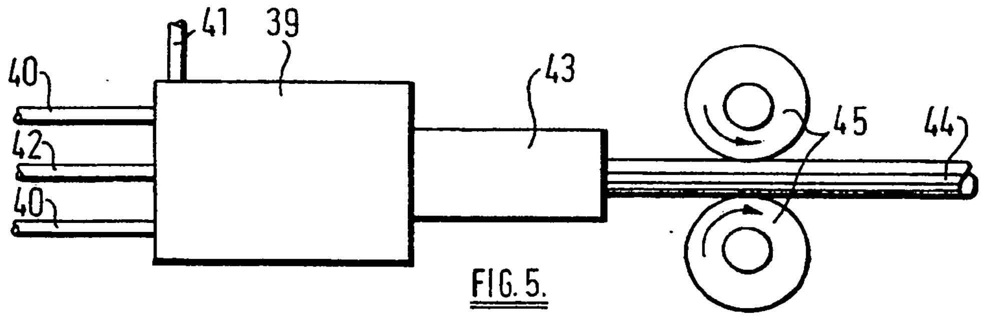


FIG. 5.

SPECIFICATION

Slurry casting of metals

This invention concerns the slurry casting of metals, also known as "rheocasting". Certain metallic materials in which the change from liquid to solid on cooling from the molten state extends over a range of temperature, during which solid crystals form, can be converted into a slurry by agitation whilst at a temperature within the range. Such a slurry can be poured or fed into a mould, whereupon it solidifies quickly with the cessation of agitation to produce a casting. The crystalline structure of such a casting is different from that of a casting produced from the same metallic material by normal casting from the molten state.

It is well established that the preparation of metal slurry requires that, during the period in which the molten metal cools and changes from a liquid to a solid, it is prevented by agitation of the melt from forming a matrix of interconnected dendritic primary crystals but, instead, the dendritic growth is modified by the agitation such that separate and discrete, individual, particles, which are primary crystal grains, are formed, the whole mass of such individual grains being suspended in the remaining liquid. Whether these suspended grains agglomerate depends *inter alia* upon the rates of shear imposed by the agitation of the melt, the temperature at which the melt is held and the surface energy of the particles. Typically, the slurries formed in this way contain between 40 and 60 *per cent* solids.

In a modification, nuclei may be introduced into the melt instead of or in addition to being precipitated from the melt. These introduced solid particles may or may not be metallic, and if they are not metallic, solidification of the resultant slurry is as a composite material.

So far as is known to the Applicant, except for a proposal to induce agitation by gas bubbling or electro-magnetic stirring, all previously-proposed methods for producing metal slurries for slurry casting have involved agitation by some kind of rotary device. For example, British Specification No 1,400,624 describes the use of counter-rotating blades mounted on vertical shafts and rotated at three to five hundred R.P.M. In other known equipment, a drum of non-uniform surface configuration is caused to rotate about its vertical axis inside a close-fitting crucible. Molten metal is introduced into the annulus between the drum and the crucible at the upper end thereof and allowed to work its way down whilst cooling. The continuous revolution of the drum provides the necessary shear forces to prevent the formation of an interconnected dendritic solid mass. The resulting freshly-formed slurry is discharged in a continuous stream from the bottom end of the crucible.

These known methods are somewhat inflexible and limit the use of slurry casting. The equipment is somewhat complex and costly and does not readily provide for the automatic handling or feeding of the slurry when casting takes place.

According to the invention, in a method of producing a metallic slurry, a metallic material is agitated by a reciprocatory agitator at a temperature between its liquidus and its solidus.

The invention includes apparatus for producing a metallic slurry comprising a vessel capable of holding metallic material in a molten condition, an agitator within the vessel and means for reciprocating the agitator.

Conveniently, the agitator may be a plate or disc, preferably having one or more perforations, secured to a rod or rods perpendicular to its major plane which may be reciprocated longitudinally. The plate or disc should be a loose fit within a crucible or vessel for the metallic material so that molten metal and solid grains may pass between its edges and the walls of the vessel as well as through the perforation or perforations if provided.

When the agitator is perforated, the or each perforation may include or have associated with it a one-way valve, for example a ball or flap valve, so that the shear forces applied to the metal slurry during movement of the agitator in one direction, in which the valve prevents flow through the perforation, are greater than those applied during movement in the opposite direction, when the valve permits flow through the perforation. Such valves are important in apparatus in which there is a space above the metallic material in the vessel and reciprocation of the agitator is in a vertical direction. The shear forces can be increased during the downward stroke of the agitator and reduced during its upward stroke to reduce the risk of cavitation by drawing air or gas into the slurry from the space above it.

The vessel is preferably of substantially uniform internal cross-section in planes perpendicular to the direction of reciprocation of the agitator, so that the clearances between the latter and the wall or walls of the vessel are substantially constant throughout the stroke of the agitator.

The agitator may have a toothed or castellated edge adjacent to the wall or walls of the vessel to increase its shearing boundary which is effective on the metallic material during reciprocation.

The vessel may have an outlet opening at one end, normally closed by a valve, so that slurry may be discharged through the opening when the valve is opened, either under gravity or preferably by movement of the agitator towards the opening so that it acts in the manner of a piston, producing a positive displacement of the slurry.

The outlet may communicate directly with a mould or die for the metallic material, maintained at a temperature below the solidus of the metallic material. With this arrangement, slurry can be discharged, for example by movement of the agitator as described, directly from the vessel into the mould, where it will solidify as a casting. If the mould is a tube of constant internal cross section, the agitator may be arranged to make successive discharges of the slurry into the mould, each discharge expelling some previously-cast metallic material from the mould so that a continuous extrusion of cast metallic material is produced. Such a continuous extrusion is a valuable precursor for subsequent processing such as forging, since the rapid

solidification of the slurry which is effected by appropriate regulation of the mould temperature produces a homogenous structure in the metallic material instead of the usual interconnected dendritic crystalline structure of a cast billet.

The invention thus includes a method of slurry casting comprising the steps of producing a metallic slurry as described above and feeding the slurry into a mould by movement of the agitator.

Apparatus for slurry casting a metallic material according to the invention comprises a vessel capable of holding the metallic material in a molten condition, an agitator within the vessel, means for reciprocating the agitator, the vessel having an outlet adjacent one end, and a mould adjacent to the outlet whereby metallic slurry may be discharged directly through the outlet into the mould by movement of the agitator.

Agitation of metallic material whilst cooling below its liquidus by means of a reciprocating agitator has advantages over the previously-mentioned methods employing rotary agitators. The method is flexible in that the speed and/or stroke of the reciprocation may be adjusted readily to provide the appropriate degree of agitation, which may be different during the initial formation of solid particles and at a later stage, for example if it is required to maintain the metallic slurry in a stable condition for an extended period. The agitator may be replaceable by others having different configurations to enable further adjustment of the degree of agitation, for example for treating different metallic materials.

By use of the agitator as a piston, as described, discharge of the slurry can be controlled, both in volume and speed. Rapid discharge may be desirable to fill a mould quickly so as to obtain a uniform homogenous structure in a product cast in the mould.

To enable the slurry vessel to be replenished quickly after a discharge has been made, the apparatus may include a second vessel capable of holding metallic material in molten condition, with a pipe or opening connecting the second vessel to the first. The molten material in the second vessel may be maintained at a temperature just above the liquidus of the material. Then, after a discharge of slurry from the first vessel, it may be replenished through the pipe or opening from the second vessel. The replenishing flow of the molten material may be assisted by movement of the agitator away from the pipe or opening. Because its temperature is only just above the liquidus, the new material entering the first vessel quickly cools to the temperature of the slurry, and as it is seeded by the crystal grains present in the slurry, the new material itself soon begins to form crystals, and the overall consistency of the slurry is not significantly changed.

The second vessel may be a crucible for melting the metallic material.

Embodiments of the invention are illustrated by way of example by the accompanying drawings in which:-

Figure 1 is a cross-sectional elevation of one form of apparatus for producing metallic slurries;

Figure 2 is a plan view, to a somewhat smaller scale, of agitators which may be used in the apparatus shown in Figure 1;

Figure 3 is a fragmentary sectional elevation of a part of an agitator including a valve;

Figure 4 is a cross-sectional elevation of another form of apparatus for producing metallic slurries, with an associated mould or die; and

Figure 5 is a diagrammatic elevation of apparatus for continuous slurry casting.

In Figure 1, a vessel or crucible 1 for holding molten metal or metal slurry has a circular cylindrical wall 2 surrounded by an insulating casing 3 within which are heating coils 4 for controlling the temperature of the charge 5 of metallic material. This temperature may be measured by thermocouples or other detectors 6 set in the wall 2 or elsewhere, and programmable circuitry (not shown) may be arranged between them and the heating coils 4 to regulate the temperature of the charge 5 according to a predetermined program.

An outlet 7 at the bottom of the vessel 1 is normally closed by a plug 8 at the end of a longitudinally-movable axial rod 9 which may be connected for operation to a hydraulic cylinder or other actuating means (not shown) above the vessel.

A transverse agitator 10, in the form of a disc having perforations 11, is a loose fit within the vessel 1 and has a central aperture 12 to accommodate the rod 9. The agitator 10 is mounted at the ends of a pair of longitudinally movable rods 13, parallel to the axis of the vessel 1. These rods 13 are connected above the vessel 1 to means (not shown) by which they can be reciprocated to reciprocate the agitator through a stroke which is variable from a maximum somewhat less than the depth of the vessel 1 to a minimum which is substantially less than the maximum. The reciprocating means may comprise a hydraulic cylinder or a rotating power source connected to the rods 13 through a variable stroke mechanism.

In use of the apparatus of Figure 1, metallic material from which a slurry is to be produced, in a molten state at a temperature above its liquidus, is supplied to the vessel 1 to form the charge 5. The charge is allowed to cool below its liquidus, the temperature being monitored by the thermocouples or detectors 6 and controlled by the heating coils 4. As the temperature of the charge falls below the liquidus, crystals begin to form, and the agitator is then reciprocated axially of the vessel 1, substantially throughout the depth of the charge 5 but without breaking the surface 14 of the charge, by longitudinal movement of the rods 13.

The reciprocation of the agitator 10 prevents substantial dendritic growth of the crystals, and further solidification of the metallic material is in the form of individual primary crystal particles, forming a slurry in the remaining liquid material in the well-known manner. The speed of reciprocation of the agitator 10 and the temperature of the charge 5 are regulated to produce the desired consistency of slurry. When this desired consistency has been achieved, the temperature may be held and reciprocation of the agitator 10 be continued to maintain the slurry until it is required for use.

When a quantity of slurry is required to be discharged, the rod 9 is moved upwardly to withdraw the plug 8 from the outlet 7, whereupon the slurry can flow through the outlet into a mould or other receiver (not shown). The discharge may be assisted by withdrawing the plug 8 when the agitator 10 is at the top of its stroke and then moving the agitator downwardly so that it acts as a piston, forcing the slurry through the outlet.

Figure 2 shows four examples of agitators which may be used in place of the agitator 10 in the apparatus of Figure 1. All are discs similar to the agitator 10, and all have a central aperture 12 to pass the rod 9. The agitator 15 has a single ring of perforations 16, whilst the agitator 17 has two concentric rings of perforations 18. The agitator 19 has a ring of radial slots 20. The agitator 21 is unperforated, but has a toothed periphery providing gaps through which the crystal particles of the slurry may pass during reciprocation of the agitator. Other kinds of agitator may also be used, the particular kind used during the producing of a particular slurry being selected according to the metallic material being processed and the quality of the slurry required.

Figure 3 shows a part of an agitator 23 having a perforation 24 adjacent to which is pivotally mounted a flap valve 25, shown in its open position, in which it is retained by an abutment 26. The valve 25 will automatically take up this position during upward movement of the agitator 23 through a slurry charge, but during downward movement the valve will be moved against the lower surface of the agitator disc, closing the perforation 24. This confines the flow of slurry to the path around the periphery of the disc, increasing the shear forces applied to the slurry in this region. Some or all the perforations of an agitator may have such valves.

Figure 4 shows another form of apparatus, comprising a circular cylindrical vessel 27 having an insulating casing 28 with heating coils 29. An agitator 30, which may be similar to any of those previously described, is mounted for reciprocation on rods 31 passing through the bottom end plate 32 of the vessel. The vessel 27 has an inlet pipe 33 through its side wall near the bottom end and a central outlet 34 in its top end plate 35 which is normally closed by a plug 36 carried by an axial rod 37. On top of the end plate 35 are slidably mounted the two parts 38 of a mould for casting products from slurry. The vessel is charged with molten metallic material through its inlet pipe 33, which is preferably connected to an adjacent crucible (not shown) in which a supply of the molten metallic material is maintained at a temperature just above its liquidus. When the vessel 27 is charged, the charge is cooled and the agitator is reciprocated to produce a slurry in the manner previously described.

To produce a casting, the two mould parts 38 are closed together and, with the agitator 30 at its lowest position, the plug 36 is withdrawn from the outlet 34. The agitator 30 is moved upwardly, forcing the slurry through the outlet 34 into the mould, and when the latter is adequately filled the plug is advanced to close the outlet. Simultaneously, new molten material is admitted through the inlet pipe 33, and after closing the outlet 34, reciprocation of the agitator is re-commenced.

The slurry injected into the mould, being at a temperature not greatly above its solidus, is cooled and rapidly solidifies, without significant dendritic growth of its crystal particles, producing a casting with a homegenous structure instead of the dendritic matrix structure which is produced in a normal casting from molten material. The mould parts are then separated to release the casting and brought together again for the procedure to be repeated. A succession of castings can thus be produced in a short time.

Provided that the temperature of the incoming molten material is maintained only just above the liquidus, this new material begins to produce crystals as soon as its joins the charge in the vessel 27, and by appropriate regulation of the temperatures and the speed and stroke of the agitator, a continuous supply of slurry of a constant consistency can be produced to enable a continuous succession of castings to be made. For controlling the temperture of the mould parts 38, they may be provided with cooling passages in the usual manner.

Figure 5 is a diagrammatic elevation of apparatus somewhat similar to that shown in Figure 4, but arranged with the axis of the slurry vessel horizontal instead of vertical. The vessel 39 is substantially the same as the vessel 28 of Figure 4, with an agitator mounted for reciprocation on rods 40, an inlet pipe 41 near its left-hand end plate and a central outlet in its right-hand end plate, normally closed by a plug carried by a rod 42. The inlet pipe 41 is connected to another vessel (not shown) in which a supply of metallic material is maintained in molten state at a temperature just above the liquidus.

Secured to the right-hand end plate of the vessel 39 is a mould or die 43 having a cylindrical cavity surrounded by cooling passages. Slurry can be discharged into the die 43 by withdrawing the plug from the outlet and moving the agitator to the right. The slurry discharged will solidify almost immediately, forming a plug partly filling the die. A further discharge of slurry can advance this plug and form a futher plug behind it, and successive discharges thus produce a continuous cast rod 44. Driven take-off rollers 45 are arranged to grip the rod 44 and draw it out of the die to assist the delivery of further discharges of slurry into the die from the vessel 39. The continuous cast rod will have the homogenous structure mentioned which cannot be produced by any other known continuous casting method.

CLAIMS

1. A method of producing a metallic slurry in which a metallic material is agitated by a reciprocating agitator at a temperature between its liquidus and its solidus.

2. A method as claimed in Claim 1 in which the agitator is a plate or disc and is reciprocated in a direction substantially perpendicular to its major plane.

3. A method as claimed in Claim 1 in which the

agitator is perforated.

4. A method of slurry casting comprising the steps of producing a metallic slurry by the method claimed in any preceding claim and feeding the slurry into a mould of movement of the agitator.

5. A method of slurry casting as claimed in Claim 4 in which the mould is of substantially constant cross section, comprising feeding the slurry to the mould in successive charges and discharging the cast metallic material from the mould as a continuous rod.

6. Apparatus for producing a metallic slurry comprising a vessel for holding metallic material in a molten condition, an agitator within the vessel and means for reciprocating the agitator.

7. Apparatus as claimed in Claim 6 wherein the agitator is a plate or disc and the means for reciprocating the agitator is arranged to reciprocate it in a direction substantially perpendicular to its major plane.

8. Apparatus as claimed in Claim 6 or Claim 7 wherein the agitator is perforated.

9. Apparatus as claimed in Claim 8 wherein the agitator includes a one-way valve adjacent to the or each perforation whereby differential shear forces may be applied to the metallic material in the two directions of reciprocation.

10. Apparatus as claimed in any one of Claims 6 to 9 wherein the agitator has a toothed or castellated periphery.

11. Apparatus as claimed in any one of Claims 6 to 10 wherein the vessel is of substantially uniform internal cross section in planes substantially perpendicular to the direction of reciprocation of the agitator.

12. Apparatus as claimed in Claim 11 wherein the agitator is a loose fit within the said cross section.

13. Apparatus as claimed in any one of Claims 6 to 12 including a second vessel capable of holding metallic material in molten condition, with a pipe connecting the second vessel to the first vessel, whereby metallic material may be delivered from the second vessel to the first vessel.

14. Apparatus as claimed in any one of Claims 6 to 13 wherein the vessel has an outlet adjacent one end and a mould is arranged adjacent to the outlet whereby metallic slurry may be discharged directly through the outlet into the mould by movement of the agitator.

15. Apparatus as claimed in Claim 14 wherein the mould has a cavity of substantially constant cross section.

16. Apparatus for continuous slurry casting comprising apparatus as claimed in Claim 15 and take-off means for withdrawing cast metallic material from the mould.

17. A metallic casting produced by the method of Claim 5.

18. A method of producing metallic slurry substantially as hereinbefore described with reference to and as illustrated by any one of the accompanying drawings.

19. A method of slurry casting substantially as hereinbefore described with reference to and as illustrated by any one of the accompanying drawings.

20. A metallic casting produced by the method claimed in Claim 19.

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